GLACIATION IN THE TELLURIDE QUADRANGLE, COLORADO

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PART III

DESCRIPTION OF DEPOSITS OF EARLIER DRIFT

RIDGES EAST AND WEST OF EDER CREEK

On the east side of Eder Creek, from the edge of the southern part of the ridge down to within 200 or 300 feet above the stream, and thence northward in an irregular belt a quarter of a mile or less from the stream, the surface shows plentiful bowlders up to 15 feet in diameter. These large bowlders are mostly rather rough and angular, and consist chiefly of Potosi rhyolite or Silverton, and Telluride. On the top of the ridge, the deposit contains fewer bowlders at the surface, their size is on the average less, and a greater variety of rocks is included—San Juan being noticeably more abundant than on the slope to the west. A striated bowlder was found on the top of the ridge at 10,500 feet. Farther north, within a quarter of a mile of the col that connects this ridge with the mountain to the north, an exposure on the west side of the ridge at about 10,300 feet shows an unstratified deposit of clay, gravel, and bowlders in variety; on some of the bowlders faint striations were observable. On the east side of the ridge, glacial drift including well-striated bowlders occurs down to about 10,400 feet, joining here with the hummocky, irregular topography which has already been described.

The boundaries of the area just described are not clearly marked on all sides, but are approximately as mapped.

This area is classed as older drift because of (1) its topographic location, far above the clearly marked limit of the recent glaciation: (2) its composition, differing as it does from the more recent drift in the presence on the surface of many large, weathered bowlders,

including Potosi rhyolite, which is unknown in the more recent drift except in small fragments; and (3) the generally more weathered appearance of the surface, especially as compared with that of the more recent drift in the valley of Eder Creek below.

The ridge west of Eder Creek above the limit of the ice in the San Miguel valley, and up to about 10,000 feet, contains on the surface fragments of rock in variety including blocks of Potosi rhyolite up to 18 feet in diameter. At several places holes a foot or two in depth expose rounded, as well as angular, bowlders in variety. No cases of undoubted striation were observed. In the forest-covered portion, but few bowlders or rock fragments could be seen; on slopes free from trees numerous small fragments, including rhyolite, occur.

On the east, the area marked by rhyolite bowlders and fragments joins the deposits made by the glacier of the more recent epoch; on the west, it extends almost to the bottom of the next small valley, about a half-mile distant.

IN THE VALLEY OF REMINE CREEK

The valley of Remine Creek is irregularly fan shaped, with low, round-topped ridges radiating from the lower part of the valley above Keystone, until they are lost in the nearly even steep slope which stretches from timber line up to the very crest of Iron Mountain. Neither on the face of the mountain to the north, nor in the valleys below is there evidence of glaciation of the more recent epoch. Exposures of drift, with a few striated bowlders, are found at the two points indicated on the map, viz.: (1) on the eastern side at elevation 9,700 to 9,900 feet, and (2) on the western side at 9,400 to 9,700 feet. At both of these points, the exposure is due chiefly to the slipping of the surface layers on a steep slope of a hill 50 to 100 feet high; bowlders in variety up to 4 or 5 feet in diameter occur, mostly well rounded, but rarely distinctly striated. Large Potosi rhyolite bowlders do not occur here as in the areas near Eder Creek.

These two drift areas in the valley of Remine Creek are referred to the earlier epoch of glaciation because of their isolated position; that is, the absence of evidence of glaciation in other parts of the

valley, together with the generally mature stage of erosion of the whole basin.

ALONG DEEP CREEK

A little more than half a mile below the junction of the east and the west forks of Deep Creek, deposits occur estimated at not less than 30 to 40 feet in thickness at a maximum. As shown on the accompanying map, they lie chiefly on the east side of Deep Creek. In topography, the surface is in part irregular, but part shows some ridges approximately parallel to the tributaries of Deep Creek from the east. In composition, the deposit contains bowlders in variety up to 3 or 4 feet in diameter, many of them rounded; none with distinct glacial striations were found.

The deposits are classed as glacial on the evidence of the topography, the heterogeneous composition, the unstratified arrangement, and the rounded, subangular forms of the included bowlders. It is classed as older drift because of its disposition, discordant with the clearly marked deposits of the recent epoch farther up the stream, and because of the absence of evidence of recent glacial action in the upper part of the valleys of the tributaries next south of the east fork of Deep Creek.

ON THE WEST SIDE OF PROSPECT CREEK

At elevation 9,900 to 10,000 feet along the road parallel to Prospect Creek, glacial drift containing striated bowlders occurs at intervals for nearly a quarter of a mile. These exposures are on the southwest-facing slope of a round-topped ridge which separates the valley of Prospect Creek from that of one of its tributaries. The slope is here wooded, and the composition of the surface deposits is largely obscured.

NEAR THE JUNCTION OF THE TWO BRANCHES OF TURKEY CREEK

Deposits near the junction of the two branches of Turkey Creek occur as follows:

1. At a point about one-fourth of a mile above the junction of the two branches, glacial débris extends 20 to 30 feet up from the stream on the north side.

2. Just above the junction of the two branches a small accumulation of glacial débris lies between the two streams, joining the

ridge which extends to the southeast from this point. Just below the junction, on the north side of the stream, a distinct ridge begins, which is continuous to the edge of the glacial deposits made by the glacier moving down Lake Fork. The crest of this ridge is from 30 to 40 feet above the stream, and numerous sections show it to contain bowlders in variety such as occur to the east. The deposits made by the Lake Fork Glacier in the more recent epoch are characterized by an abundance of the light-colored granitic phase of the diorite-monzonite intrusions farther up the valley; but this diorite-monzonite is absent from the morainal ridge north of Turkey Creek just below the junction of the two branches. At the point where the stream crosses the eastern edge of the moraines of the Lake Fork Glacier, an exposure of drift on the south side of the stream about 75 feet in height shows diorite-monzonite bowlders in abundance and near the top of the exposure on the east side some stratified drift.

Above the deposit (1), named above, the course of the north branch of the stream lies in a narrow, steep-sided channel, in which are exposed enormous masses of Telluride and San Juan rocks tilted at angles up to 45° upstream; no recognizable drift occurs near the stream until the boundary of the moraines already described is reached, at elevation 10,100 feet. The valley of the south branch of Turkey Creek above the junction has a gradient less steep than the north branch, but in this direction also no drift is recognizable until at the mouth of the first small tributary from the east an alluvial fan shows bowlders evidently derived from the edge of the glaciated tract a half-mile to the east. A little farther up the stream, the western slope has a covering of bowlders in variety continuous with the deposit next to be described, which covers the southern end of the 10,100-foot hill lying west of the south branch of Turkey Creek at this point.

The deposits lying near the junction of the two branches of Turkey Creek are classed as older drift because of (1) their composition, which is different from that of the Lake Fork glacial deposits to which they are adjacent; (2) their position in a narrow valley which meets the edge of the Lake Fork Glacier in an angle acute in the direction of motion of the glacier; and (3) the unglaci-

ated channel of the stream for three-fourths of a mile above the highest of the deposits.

WEST OF THE SOUTH BRANCH OF TURKEY CREEK

On the southern end of the 10,100-foot hill west of the south branch of Turkey Creek, glacial débris extends from 10,100 feet elevation down to the stream on the east. The surface here consists of arkose soil with numerous bowlders, some rounded and some angular. On the south side at about 10,000 feet elevation a bowlder of Potosi rhyolite, 18 feet in diameter, has distinct glacial striae on a part of its surface where it has been measurably protected from weathering. Other Potosi rhyolite bowlders are found, one as much as 12 feet in diameter.

About one mile east of south from this hill on a southwestward-facing slope an exposure of drift occurs at elevation about 10,100 feet; the soil here also is arkose containing bowlders in variety, a few of which are striated. This area is continuous over the top of the ridge to the northeast, down to elevation about 10,000 feet.

These deposits are classed as older drift because of (1) their topographical position, 300 feet above the edge of drift of the more recent epoch; (2) their composition, including large bowlders of Potosi rhyolite which is unknown in the more recent drift except in small fragments; and (3) the weathered character of the material as shown by the arkose soil.

DIAMOND HILL, AND OTHER ADJACENT POINTS

Deposits classed as older drift are found on Diamond Hill (Fig. 15) and on other elevated points on the mesa between Big Bear Creek and Bilk Creek, as shown on the map (see Part I). The deposits in all these places so closely resemble each other in composition and general appearance that it would be impossible to distinguish one from the other if all were transferred to one place. The one most noticeable characteristic common to all is the presence of rather irregular bowlders of Potosi rhyolite from 4 to 10 feet in diameter, the larger size being the more frequent. Besides the Potosi rhyolite, other varieties of rock commonly present are basalt, diorite, diorite-monzonite, Telluride, quartzite, feldspar porphyry,

sandstone, and shale. Many of these bowlders, even of the hard varieties such as diorite, are well rounded. It is noteworthy that San Juan bowlders are absent. Striated bowlders were found in only one of the areas mapped, that is in the area lying east-west about three-quarters of a mile north of east from Diamond Hill. The deposit on Diamond Hill ranges up to 10 or 20 feet in thickness; the thickness at other points is not easily estimated, but may reach

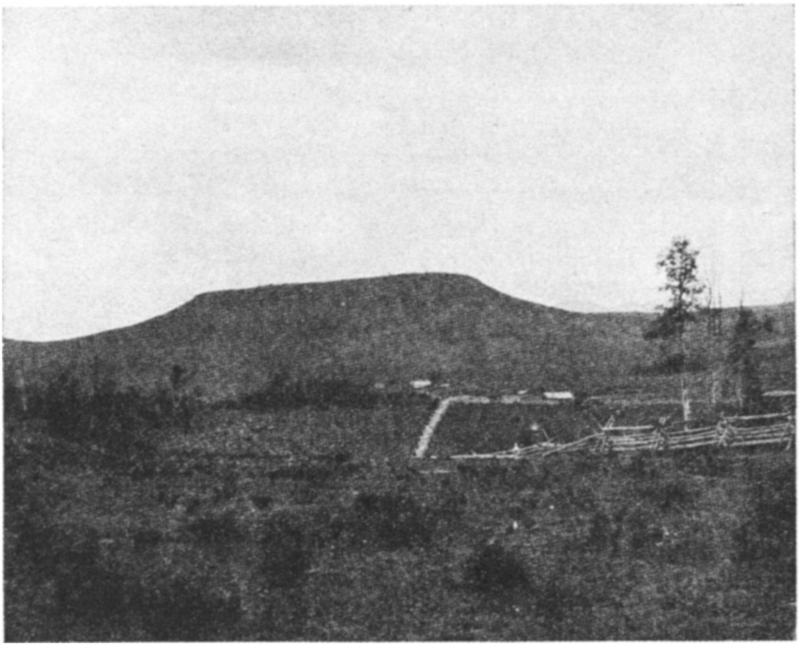

FIG. 15.—Diamond Hill elevation 10,100 feet. Looking northeast from elevation 9,400 feet. Glacial drift of the earlier epoch covers the northern (left-hand) end of this mesa.

50 feet for the area three-quarters of a mile north of east of Diamond Hill.

These deposits are classed as older drift because of (1) their position, in disconnected patches on points ranging up to 500 feet higher than the nearest drift of the more recent epoch; and (2) their composition, including prominent bowlders of Potosi rhyolite which is not characteristic of the more recent drift.

ALONG THE STREAM SOUTHWEST FROM BLACK FACE MOUNTAIN

In the valley of the small stream heading at 10,600 feet elevation west of south of Black Face Mountain, glacial drift is exposed at intervals up to 10,700 feet. Clearly striated bowlders occur at 10,400 feet; at 10,500 feet bowlders in variety include Potosi rhyolite, the largest about 20 feet in diameter. Above 10,700 feet no glacial drift or other signs of glaciation are found.

This deposit is classed as earlier drift partly because of its composition, including large Potosi rhyolite bowlders, but chiefly because of the lack of evidence of glaciation in the upper part of the valley.

NORTH SIDE OF EAST DOLORES RIVER

North of the terminal portion of the glaciated tract in the valley of the East Dolores, rounded and subangular bowlders in variety occur at intervals up to elevation about 10,100 feet, that is, to a height of 400 feet above the upper limit of drift of the more recent epoch. The varieties most frequently found are diorite-monzonite and Telluride, with fragments of sandstone which is here the underlying formation. No good exposures or sections occur in this area, and no striated bowlders were found. The deposit is classed as drift because of its composition and its abundance. It is classed as older drift because of its topographic position and considerably weathered surface.

EAST SIDE OF EAST DOLORES RIVER

On the east side of the East Dolores River, above the mouth of the branch heading at Lizard Head Pass, a belt about three-eighths of a mile wide above the upper limit of glaciation as mapped for the more recent epoch contains occasional deposits of bowlders in variety, and an irregular topography including at the southern end of the belt some undrained depressions. The irregularity of the topography is, in part, clearly due to landsliding, but striated bowlders found in some parts of the area are evidence that the surface deposits include glacial material. As has already been stated, this belt is classed as older drift because of its topographic position, high up on the slope, and because of the relative scarcity of the drift in this belt as compared with the deposits of the more recent epoch near the stream.

NORTH SIDE OF STREAM HEADING WEST OF GRIZZLY PEAK

On the north side of the stream, outside the limit of glaciation of the more recent epoch, and extending down the valley to elevation about 10,600 feet, rounded and subangular bowlders are mingled, with shale fragments, including Telluride up to 8 feet in diameter, monzonite, and other forms of igneous rock. This area is classed as older drift chiefly because of the striking difference in topography, as compared with the newer drift above 10,700 feet elevation. At the limit of the more recent drift as mapped, the surface of the moraine near the stream is 150 feet above the bottom of the valley with a westward-facing slope of 30° to 35°. In the older drift area outside, the hillocks are low, with flattened crests and gentle slopes.

On the south side of the stream in the area of more recent drift, moraines also occur; on the south side of the stream opposite the older drift area, as mapped, are precipitous faces of outcropping rock or slopes of talus.

AREAS BETWEEN SHEEP MOUNTAIN AND EAST DOLORES RIVER

The area west of Sheep Mountain is for the most part heavily wooded, and the surface deposits are much obscured. At two places, however, glacial deposits were found. One area is at about 10,400 feet elevation, half a mile south of the limit of glaciation, as mapped, for the more recent epoch. It consists of a short ridge extending in a northeast-southwest direction, with some irregular topography including kettles on the west, and a nearly level area to the east joining the steeper slope above. An exposure on the western side of the ridge shows the usual composition for moraines. The other area includes deposits found near the stream which heads west of Sheep Mountain. From elevation about 10,400 feet up to 11,600 feet, drift occurs nearly continuously near the stream. For about a quarter of a mile above 10,500 feet elevation on the right side of the stream is a distinct ridge with top 30 to 40 feet above the bottom of the valley; this ridge consists of typical glacial débris, including striated bowlders. On the left side of the stream opposite this moraine, and on both sides up to 11,600 feet, the glacial deposit is often merely a surface covering, showing no distinctive topography characteristic of glacial deposits. Striated bowlders were found at 11,600 feet on the left side of the stream.

Below 10,400 feet occasional accumulations of gravel and bowlders in variety occur as far as the limit as mapped for ice of the more recent epoch. Much of this débris below 10,400 feet cannot be distingüished from valley train deposits, and is therefore not included in the area of older glaciation.

So far as composition and position are concerned, the deposits in these two areas west of Sheep Mountain might be referred to glaciation of the more recent epoch. They are classed as older drift because the valleys on the western side of Sheep Mountain from which it seems they must have been derived do not present the evidences of glaciation such as are found in the other high valleys which are known to have been occupied by glacial ice in the more recent epoch. It is possible that, with the fuller examination of this area which could be made if the forests were removed, relations of the drift of these areas may be established which will result in its reference to the more recent glacial epoch.

OTHER AREAS

At numerous other points, especially on the mesas between Remine Creek and Deep Creek, and again on points and ridges north of the East Dolores River, patches of bowlders occur which closely resemble glacial drift. But either because of poor exposure of the deposit, or because no striated bowlders could be found, these areas have not been mapped. Although not recorded because the evidence is considered insufficient to warrant their classification with undoubted glacial deposits, it is nevertheless believed that in many cases they represent remnants of former moraines, or possibly in some cases outwash plains from glacial sheets of an earlier epoch.

LANDSLIDES

Although not to be classed as glacial phenomena, a brief discussion of landslides and the topography resulting from them in the quadrangle is necessary because areas occur which present at the same time some of the characteristics of areas in which the materials have come to their present position by sliding or slumping, and some of the characteristics of typical morainal deposits. In most of the works previously cited reference is made to the frequent occurrence of landslides in the San Juan region, and in one, *Pro-*

fessional Paper 67, Mr. Howe has considered their occurrence and causes at length, and has called attention to the fact[1] that under certain circumstances masses of material moved by landsliding and masses deposited as glacial moraines may resemble each other so closely as to give rise easily to errors in interpretation. As criteria in such cases Mr. Howe says that "recourse must be had to strictly geologic evidence—that is, the condition and character of the material and its relation to rock in place."

In a discussion of the same problem as presented in the Uinta Mountains, Mr. Wallace W. Atwood[2] lays especial emphasis on the value of topography and topographic relations in the determination of doubtful cases of this kind, saying that "the chief criteria used have been, first, the topography of the material; second, the topography of the basin or valley affected; and third, the topographic relations in the basin or valley."

It is of course necessary constantly to bear in mind the fact that, so far as the region under consideration is concerned, the question usually most difficult to decide is not whether a given mass of material has its present form and position as a result (1) of glacial action exclusively, or (2) of landsliding exclusively; but that it is as a rule a very different one, embracing two distinct phases, viz.: (*a*) to determine with some degree of accuracy what share each of the two classes of agencies referred to above may have had in determining a given arrangement and location of débris; and after this is done, (*b*) to decide how completely the work of each class of agencies is to be represented on a map showing the geology of the region. Or, stated briefly and in order, the points to be ascertained about such doubtful areas are:

I. Agencies involved.
   1. Glacial action to the exclusion of landsliding.
   2. Landsliding to the exclusion of glacial action.
   3. Glacial action with later landsliding.
   4. Landsliding with later glacial action.
   5. Various successions and alternations of glacial action and landsliding.

[1] *Op. cit.*, pp. 16 and 17.

[2] *Professional Paper 61, U.S. Geological Survey*, pp. 63–65.

II. In the case of (3), (4), or (5), percentage of total action represented by each of the two agencies.

III. In the case of (3), (4), or (5), is the area to be mapped as landslide or moraine?

It is to be noted in regard to the points named above that as regards I, 1, it is highly probable that in strict literalness there is no morainal deposit anywhere which has not subsequently been subject in some degree to a settling and shifting of its materials, and if the deposits have had steep slopes some of these movements would no doubt deserve the name of landsliding; the same thing must necessarily be true of morainal deposits laid down on steep slopes of underlying material of whatever nature, or on any slope which is made up of materials which are themselves creeping, slumping, or sliding; but in many cases the amount of readjustment of material has evidently been so small that the effects due to landsliding may be disregarded. As to point III above, the question of representation on an areal map may sometimes be difficult to decide. It would seem that on a general areal map that agency should be represented which has clearly had the larger share in the transportation of the material at or near the surface; this necessarily means that agency which has most recently accomplished a notable amount of transportation of materials at or near the surface. On a map drawn to show especially glacial phenomena, even a small percentage of glacial débris may properly determine the inclusion of the area within the glaciated tract. Another method combining both of the above, used on the areal sheet of the *Engineer Mountain Folio*, is at times very desirable, especially in the case of valleys where the drift is in general small in amount, viz., to indicate the upper limit of glaciation by a definite line, and within the glaciated area to map moraines, landslides, bed rock, etc., as the character of the surface in the respective cases may warrant.

On the map (see Part I) the purpose has been to show clearly the maximum extent of glaciation in the recent epoch, and consequently no account has been taken of the fact that at some points within the areas indicated the débris has been notably readjusted in position by creeping, slumping, or sliding; this is especially true

(1) of the areas indicated as landslide near Trout Lake on the areal map of the *Telluride Folio*, and (2) the tongue of the landslide area extending to the westward down the east slope of the valley of Lake Fork, 4 to 5 miles south of Keystone. As noted in the detailed descriptions of glaciated valleys, there are numerous striated bowlders in the two regions referred to, but there has also been a marked amount of slipping and readjustment of material, so that the application of the principle laid down above, namely, that the most recent agency to produce notable results should take precedence, would require the mapping of landslide areas on an areal map practically as shown in the folio. The application of the same principle results, however, in some reduction of the area referred to as the Silver Mountain landslide by Mr. Howe.[1] For, as noted in the description of the upper part of the valley of Prospect Creek, and of the area west of Turkey basin and Alta basin, the topography and materials are in both cases characteristic of glacial action rather than of landsliding for some distance within the boundary of the landslide area as mapped in the folio. It is to be said, however, that the lower limit of the glaciated area as shown on the map (see Part I) is drawn somewhat arbitrarily, since the characteristics due to glacial action as already described, and those due to landsliding, are mingled together near the boundary in a manner which makes an accurate determination of the share which each had in the movement of materials difficult, or sometimes impossible.

With respect to the time relations involved in the landsliding, reference has already been made to observations which prove conclusively that some of the movements antedated the epoch of the more recent glaciation, as for example the great block of Potosi rhyolite two and one-half miles south of east of Trout Lake (Fig. 7). The well-cleaned-out cirquelike valley head to the northeast of this block, as well as the typical ground moraine topography of the glacial drift west of Turkey basin and Alta basin, shows that, at these points at least, the amount of landsliding since the recent glacial epoch has been insignificant, even though other areas near by in each case show evidences of a considerable amount of movement since the ice withdrew.

[1] *Op. cit.*, p. 17.

ROCK STREAMS

Within the Telluride quadrangle there are in all about 20 of the peculiar accumulations of angular rock fragments to which has been given the name of rock streams or rock glaciers; the location of the most of these is shown on the map (see Part I). The characteristics of such areas have been noted by various observers in this region, although none were recorded for this quadrangle at the time the folio was published. They occur for the most part at an altitude of 11,000 feet or more above sea-level, in cirques or in the upper portion of valleys at about the elevation at which cirques occur, usually at the base of precipitous walls of rock. They extend in some cases for as much as a quarter of a mile down the somewhat flattened bottom of the cirque, and rise as much as 20 to 30 or even 40 feet above the bottom of the narrow, valley-like depressions which separate them from the slopes of talus at the base of the side walls, as in the valley of the stream tributary to Mill Creek heading west of Dallas Peak. In other cases the rock stream consists of a belt or band of rock fragments lying approximately parallel to a steep cliff face, the distance covered being less in a direction perpendicular to the cliff than in the direction parallel to it, as in the valley of Canyon Creek east of Gilpin Peak, and in Middle basin, a tributary of the valley drained by Marshall Creek. In still other cases the rock stream covers an irregular area, but is located at about that part of the valley head where snow and ice collected in the winter would evidently be likely to be largest in amount, and protected in such a way as to be likely to remain longest in the spring, as for example the small area at the head of Turkey basin (Fig. 9).

In topography the surface of these areas resembles moraines in the following respects: (1) the elevations are usually in the form of ridges, sometimes irregular in arrangement, sometimes transverse to the direction in which the mass is being moved, and sometimes parallel or subparallel to the direction of movement; (2) between these ridges are many irregular depressions, corresponding to the kettles of typical morainic topography, having dimensions up to 100 by 25 feet and usually not more than 10 to 15 feet in depth, though one exceptional area in Middle basin has a depression 50 to

60 feet in depth. As to the outer boundary of these areas, the degree of slope is often as steep as can be formed by the fragments composing it. This is true both of the sides where the rock stream extends as a tongue down the valley, and of the lower end or terminal portion. In some cases, as in the area in Turkey basin (Figs. 10 and 11), the fragments making up the outer slope were found so insecure in their position as to make climbing difficult, numerous fragments sliding and falling down the slope whenever an attempt was made to secure a foothold.

In a few cases, as for example in Middle basin, a valley tributary to the valley drained by Marshall Creek, in the upper part of the valley of the tributary of Mill Creek heading west of Dallas Peak, in Savage basin, and in Ingram basin, rock streams of at least two distinctly different ages occur. The more recent is composed of fragments fresh in appearance, angular, and bare except for lichens on some of the surfaces. In the case of the older, the rock fragments are much disintegrated, so that the crests of the ridges are less sharp, and soil enough has accumulated to support vegetation, making the surface appearance that of rounded, green hills instead of bare ridges of angular fragments. These rock streams of earlier age usually lie at the lower or outer edge of the corresponding areas of more recent date, but in at least one case, in the upper part of Savage basin just beyond the eastern boundary of the quadrangle, the stream of unweathered fragments has passed around and beyond a small area of the earlier, appearing to have been deflected in its movement as by an obstacle, but spreading out again below the obstruction after having passed it.

To account for the presence of these accumulations of rock fragments two principal causes have been assigned, namely, (1) landslides, moving "with a sudden violent rush that ended as quickly as it started," and (2) the effect of the presence of interstitial ice, cementing the fragments together, and producing with changes of temperature a movement similar to that of glaciers. The former view is advanced by Howe in *Professional Paper 67, U.S. Geological Survey*, p. 54; the latter by Capps, in the *Journal of Geology*, XVIII (May-June, 1910), 362–64. Each of these authors recognizes other possible causes, but considers such others as may

be present as of minor importance. So far as the observations made by the author of this paper in the Telluride quadrangle give a basis for conclusions, it appears that these accumulations of rock fragments are due primarily to the work of ice as indicated by Capps in the article just referred to. The reason for assigning this cause as the principal one in the case of the rock streams in this quadrangle may be summed up from the descriptions already given as follows:

1. The topography of the surface, consisting of irregularly disposed ridges and kettle-like depressions.

2. The steep slope of the outer boundary, formed of fragments insecure in position, showing that they have been but recently moved to their present place.

3. The considerable distance which much of the material has been moved from the cliff from which it has been derived.

4. The location of these areas at elevations practically the same as that at which crevassed *névé* ice was reported "on the north slope of the high ridge east of Dallas Peak."[1] When this slope was visited in August, 1905, no mass of ice was visible, but rock streams were observed both on the north slope of this ridge and over the divide east of Gilpin Peak.

5. The location of a considerable number of the rock streams in positions where snow and ice would be most likely to accumulate in large amount, and likely also to be best protected from the sun's rays. The larger areas are, of course, found in positions directly exposed to the rays of the sun, but the smaller ones are far more abundant at the foot of northward-facing, or northwestward-facing precipitous slopes.

6. The relation in position of the rock streams of two distinctly different periods of movement in which the later appear to have moved around the earlier, deploying after passing the latter as in the case of actual glacial movement.

If the interpretation here given of the above phenomena is correct, the rock streams in this quadrangle are to be considered as representing incipient glacial movement. With respect to the last period of glaciation such movements are clearly to be regarded as

[1] *Telluride Folio*, p. 15.

part of the last, feeble, intermittent struggles of the glacial forces which earlier in the epoch acted with such vigor in the same region.

SUMMARY AND CONCLUSIONS

TOPOGRAPHIC EFFECTS OF GLACIATION

1. *Cirques.*—Almost all valleys in the quadrangle which have as much as half a mile of their course above 11,000 feet in elevation were occupied by glaciers in the more recent epoch; at the heads of many of these valleys cirques were developed. A typical cirque may be considered as having (1) a nearly perpendicular bounding wall, semicircular in plan, and (2) a comparatively level bottom. In a few places this typical plan is closely approximated; in most cases, however, there is variation in many ways. The bounding wall may be only a small arc of a circle, making the resulting cirque a broadly open one; or the nearly perpendicular faces of rock may be prolonged on each side of the valley for a mile or more in the downstream direction, producing a deeply recessed valley head which approximates the linear form characteristic of valleys. The slope of the bounding wall as a rule approaches perpendicularity only at some distance above its base—usually not more than the upper one-half of the vertical height of the wall shows the steep faces left by falling blocks or fragments (Fig. 9); at the base in almost all cases are slopes of waste, generally in the form of bare rock fragments, but occasionally so far weathered as to furnish a soil where an Alpine flora can gain sufficient foothold to cover the surface in the summer months with a carpet of green. The bottoms of the cirques also present variations. In some cases much of the floor is rock in place, frequently grooved and striated, and containing depressions in its surface in which are shallow lakes varying in size up to one-fourth of a mile or more in diameter. In other cases the floor is covered in whole or in great part with rock fragments and soil; the bottoms of such cirques are as a rule more irregular and less nearly horizontal than in the case of the cirques which contain lakes. Rock streams, already described, are found only in cirques or in the upper parts of valleys at a corresponding elevation.

2. *Hanging valleys.*—Numerous hanging valleys occur in the quadrangle; in most cases they were themselves occupied by

glaciers; in all cases the valleys to which they are tributary were glaciated. As to mode of formation, the hanging valleys in this quadrangle may be divided into two classes, viz.: (1) those due primarily to glacial deposition; (2) those due primarily to glacial erosion.

The valley of Prospect Creek is an example of class (1). The lower course of this stream was covered by glacial ice moving down the valley of the San Miguel River to which it is tributary, and the morainal deposits left by that glacier across the course of Prospect Creek have been eroded only in part by the stream, leaving the bottom of its valley just outside the moraine still about 350 feet above the level of the San Miguel River. Deertrail basin is an example of class (2). The bottom of this valley is about 1,500 feet above the level of the valley of the San Miguel River to which it is tributary. There is no means of determining just how much of the valley of the San Miguel was lowered by glacial erosion at this point, but from an examination of other tributaries near, it does not seem probable that it could have been more than a very small part of the 1,500 feet mentioned above. That the San Miguel valley was much less flat-bottomed in pre-glacial time than now hardly admits of question; the present steepness of the valley wall at the point where the stream from Deertrail basin enters must therefore be due primarily to lateral erosion by glacial ice. As has been pointed out by Russell,[1] this widening of a valley at the bottom is entirely sufficient to produce the phenomena of hanging valleys in the case of tributaries with a steep gradient. The very small size of Deertrail basin, however, together with the fact that the lower end of the basin is approximately at the same level as was the surface of the ice in the valley of the San Miguel River, indicates that the conditions of glacial erosion primarily responsible for making this basin a hanging valley are those stated by Russell for mountain-side glaciers,[2] viz., a gully or other depression occupied by a small glacier whose downward limit of erosion was a distance above the bottom of the main valley equal to the thickness of the ice in the main valley less the thickness of ice in the tributary.

[1] *Bulletin of the Geological Society of America*, XVI, 80.

[2] *Ibid.*

In this connection it should be noted that not all the valleys tributary to valleys which were occupied by glaciers are hanging valleys. For a given stream it may occur that part of the tributaries occupy hanging valleys, while a part are in topographic adjustment with the main stream. For example, east of the city of Telluride the San Miguel River receives tributaries from glaciated valleys as follows: Bear Creek, Deertrail Creek, Bridal Veil Creek, Ingram Creek, and Marshall Creek. Of these, Deertrail basin, Bridal Veil basin, and Ingram basin are hanging valleys, while Bear Creek valley and Marshall basin cannot be so classed. Of the two larger tributaries from the south, Bridal Veil Creek enters the cirquelike head of the San Miguel valley by a sheer fall of 350 feet and with a steep grade below for another 500 feet of fall before it reaches the more level part of the bottom of the valley; while Bear Creek, two miles farther west, draining a glaciated area less than that of Bridal Veil basin, enters the San Miguel River by a grade no steeper than is usual for mountain streams. Other things being equal, it would seem that a valley draining a small area would be deepened less by glacial action than one draining a larger area; and if so, then the smaller valley would be more likely to be left as a hanging valley. However, Bear Creek valley, the smaller one in this instance, is not a hanging valley, while Bridal Veil basin, the larger one, is; some modifying conditions have therefore evidently been present.

A modifying condition in this case may be (1) the difference in kind of rock forming the bottoms of the valleys. In Bridal Veil basin the San Juan formation is the underlying rock, while in the larger part of the valley of Bear Creek the more easily eroded sedimentary rocks of the Jura-Trias period outcrop in the bottom for two miles or more. Or the modifying condition may be conceived to be (2) a difference in the pre-glacial topography. If the grade of Bear Creek in pre-glacial time was not steep in its lower course, and if the downward cutting of the ice in the San Miguel valley was but little different in rate from that in Bear Creek valley, a hanging valley would not be formed. And on the other hand, a steep gradient in Bridal Veil Creek in pre-glacial time would, according to the principles already referred to in the case of Deertrail

basin, be sufficient to account for the lack of topographic adjustment as seen today. A complete explanation of the present difference between these two valleys must, without doubt, include both of the modifying conditions (1) and (2), just named

In the case of Marshall Creek, only the second of these two modifying conditions can apply. This stream enters the San Miguel valley from the north at a somewhat steeper grade than does Bear Creek from the south, yet there is no abrupt change to a steep grade in its lower course such as is characteristic of streams in hanging valleys. Comparing again with Bridal Veil basin, the area drained by Marshall Creek is considerably less, so that so far as wear of channel due to ice alone is concerned it would seem that the valley of Marshall Creek would have been lowered by a less amount than was the valley of Bridal Veil Creek. The rock exposed in the bottoms of the two valleys is in this case the same, so that the only other modifying condition which appears to be sufficient to explain the difference seen today is that of the pre-glacial topography. That is, a gradient in pre-glacial time considerably less steep for Marshall Creek than in the case of Bridal Veil Creek or Ingram Creek is sufficient to cause the present difference. If this conclusion in the case of Marshall Creek be correct, it would seem probable that the modifying influence of pre-glacial topography predominated also in the case of Bear Creek, aided in a subordinate way by the presence of sedimentary instead of igneous rocks in the lower part of its course.

3. *Rounded topographic forms.*—Topographic forms rounded in outline due to glacial action, in contrast with the angular outlines usually found in unglaciated, mountainous areas, occur at many points in the quadrangle; they may be grouped as to origin in two classes, namely, (1) those due primarily to glacial erosion; and (2) those due primarily to glacial deposition. Class (1) includes (*a*) rounded, projecting points or masses of rock in place of which *roches moutonnées* are the type; and (*b*) valleys having a U-shaped cross-section as opposed to the sharper V-shaped section characteristic of unglaciated mountain valleys of steep grade. Class (2) consists of morainal deposits of various kinds, forming low, round-topped hills or ridges; sometimes these hills are in the bottoms of

valleys, as in the valley of the San Miguel River near Keystone (Fig. 4); sometimes they are on the tops of mesas 1,000 to 1,200 feet above the bottoms of the adjacent valleys, as on the mesa lying between Bilk Creek and Lake Fork.

4. *Silted-up lakes and ponds.*—Nearly level areas due to the silting-up of ponds or lakes occur at several points in glaciated valleys. The largest of these areas is in the valley of the San Miguel River (Fig. 3); it has a length of nearly five miles and a width of about half a mile. For the greater part of its course through this area the San Miguel River has a grade averaging about 30 feet per mile. In some parts of its course the grade is much less than this and the stream flows in wide meanders. At one point the generally level surface of this lacustrine plain is somewhat broken by low morainal hills; in other places it has been slightly modified by the accumulation of material in post-glacial time in the form of alluvial fans, a kind of modification to which practically all similar areas in the quadrangle are subject.

5. *Terraces and valley trains.*—Beyond the termini of the various glaciers, drift in the form of stratified deposits is usually found at intervals along the sides of the valleys, sometimes evident as narrow terraces or remnants of terraces. In the case of the San Miguel River these deposits extend beyond the boundary of the quadrangle, and are found at elevations up to 100 feet above the stream. The amount of débris left as valley trains is slight owing to the narrow, steep-sided valleys in which the streams flow.

CHARACTERISTICS OF THE DEPOSITS OF DRIFT OF THE EARLIER AND THE LATER EPOCHS

The drift deposits of the earlier and the later epochs are alike in being made up of a heterogeneous mixture of rounded and subangular rock fragments of various kinds and various sizes, including some bowlders and pebbles with striations.

The most important differences are with respect to (1) the kinds of rock present, (2) the topographic position of the deposits, and (3) the amount of erosion which has taken place since the withdrawal of the ice sheets to which the deposits of the two epochs, respectively, owe their origin. As to composition the drift of the

earlier epoch or epochs is characterized by bowlders of Potosi rhyolite up to 18 feet in diameter; that of the more recent epoch by bowlders of diorite-monzonite up to 4 feet in diameter, or of the San Juan formation up to 15 feet or more. Striated bowlders are, in general, rare in the earlier drift; in the more recent drift they are of common occurrence, and locally are abundant. As to topographic position, the deposits of earlier age occur in the majority of cases on the tops of mesas or ridges ranging up to 500 feet or more above the upper limit of the adjacent deposits of the more recent epoch. Some of the earlier drift, however, lies on slopes and in valleys in contact with the upper limit of drift of the more recent epoch just as if the earlier drift sheet had been in part overridden by the more recent glaciers. Not only does the older drift usually lie at a higher elevation than the more recent, but it also lies outside the drift boundary of the latter. In one case the earlier drift is found in a valley in which the more recent drift is not represented; in other cases the older drift lies at distances ranging up to one and one-half miles beyond the edge of the more recent deposits.

The difference in the amount of erosion to which the drift of the two epochs has been subject is shown both by the general field relations and by the topography of the deposits. The earlier drift deposits constitute in quantity a comparatively insignificant amount of material, distributed in isolated, small patches, at not less than twenty-five different places in the quadrangle. The more recent deposits, on the other hand, include prominent moraines and drift sheets which are in general continuous for each valley or drainage basin in which they occur. In topography, the earlier drift is characterized by a surface of greater regularity and smoothness, and by an absence of undrained depressions; the more recent drift, on the other hand, in a number of places shows a much more irregular surface with numerous kettle holes.

EXTENT OF GLACIATION

1. *In the more recent epoch.*—The number of glaciers occupying valleys in this quadrangle in the more recent epoch can be stated only in terms of number of terminal areas, and number of areas in which movement of ice originated. It must be remembered,

however, that this method of statement does not present complete information as to the number of glaciers which existed, for on each side of the quadrangle glaciers moved to undetermined termini beyond its borders; and on two sides glaciers moved into the quadrangle from points of origin outside. Within the quadrangle, however, there are between 80 and 90 points of origin, the exact number reckoned depending upon how many of the smaller tributaries of a given valley are considered as independent areas of initial movement. Of termini there are 14.

The total area glaciated in the more recent epoch is estimated at near 150 square miles. The greatest length of glacier lying wholly within the quadrangle, measured from terminus to most remote point of origin, is $15\frac{1}{2}$ miles. Some of the glacial ice within this quadrangle, however, was tributary to the great Animas Glacier which is reported by Mr. George H. Stone[1] to have been 60 miles or more in length.

The maximum thickness of ice was probably something in excess of 1,500 feet. The slope of the surface of the ice varied from probably 1,000 feet per mile in the upper part of small valleys to 200 feet per mile or less in the lower part of the course of the larger glaciers.

The amount of glacial erosion cannot be estimated accurately from the deposits which are found, owing to the fact that much of the débris must have been carried away by the swift streams. But even when allowance is made for the disappearance of a considerable amount, it would seem that the whole amount removed by the ice was not in excess of 100 to 200 feet in average thickness for the glaciated tract; the maximum amount of erosion may, in places, have reached 400 to 500 feet.

As already stated in the description of the drift in the valley of the San Miguel River, the deposits near Keystone may be as much as 400 feet in thickness; this depth of drift is, however, very unusual for this quadrangle. Outside of the Keystone deposits the thickest are probably those found on the mesa between Bilk Creek and Lake Fork. The maximum height here of the top of the morainal hills or ridges above the bottom of the adjacent

[1] *Jour. Geol.*, I, 471 ff.

valleys is about 1,200 feet. This is not, however, a measure of the thickness of the glacial deposits, but is an indication of about the maximum thickness reached by the glacier at the point in question. The morainal deposits cannot exceed from 200 to 300 feet in thickness, and may be considerably less. The greater part of the total elevation of the top of the morainal hills above the bottom of the valley is due to the underlying rock in place which constitutes the walls of the canyon-like valley down which the glacier moved.

2. *In the earlier epoch or epochs.*—The occurrence of the older drift at and beyond the edge of the more recent drift is conclusive proof that the earlier glaciers covered a greater area than the more recent ones. With the exception of a few square miles in the northwestern part and possibly also in the southwestern part the entire area of the quadrangle must have been affected by glaciers in the earlier epoch. The appearance of the surface for a considerable length of time in that epoch must, therefore, have been that of snow and ice, except as it was broken here and there by projecting tops of peaks and ridges on whose steep slopes the snows could find no resting-place. In view of the great extent of the glaciers of the earlier epoch, and the large size of the bowlders which constitute a part of their deposits, glacial action in that period must have been sufficiently vigorous and long continued to produce important modifications in the topography. The details of such changes, however, can never be known; we can only be sure that the glaciers of that period played no small part in the general process of degradation which is still going on in the region. The isolated patches of earlier drift which are seen today are believed to be remnants of the moraines of that early period; those moraines must have retarded the erosion of the formations on which they were deposited, and so the elevation of the mesas and ridges on which these patches of drift occur must be somewhat greater than it would have been except for the protection thus afforded. Without doubt, therefore, some of the hills and ridges in the quadrangle owe part of their present elevation and some details of their configuration to the work of glaciers in the earlier epoch; but there are no means at hand by which to determine even approximately the amount of modification due to this cause.

AGE OF THE DRIFT

1. *More recent epoch.*—The age of the more recent deposits of drift is to be regarded as the same, in general, as that of the deposits of the Late Wisconsin stage of the continental ice sheet which covered the northern part of North America in Pleistocene time. It is evident, however, that the ice persisted in the upper parts of valleys until within very recent time, as shown by the crevassed *névé* ice reported a few years ago from the northern part of the quadrangle,[1] and by the signs of recent glacial movement seen in the rock streams, previously described in this paper. While correlated with the Wisconsin stage of the continental glacier, it is for the reasons just given to be understood that glacial ice remained in the quadrangle for a very considerable period after the continental ice sheet had disappeared from the northern part of the United States east of the Mississippi River.

2. *Earlier epoch or epochs.*—In considering the age of the earlier drift deposits it is to be observed that the drift referred to an earlier epoch or to earlier epochs of glaciation may be grouped as to position in two classes, viz.: (1) that found frequently on the tops of mesas or ridges, sometimes on slopes, at elevations ranging up to 500 feet above the upper limit of the nearest glacial deposits of the more recent epoch, and at distances ranging up to one and one-half miles beyond the edge of the more recent deposits; and (2) that found in valleys whose upper portions lack the usual evidences of recent glaciation.

It is to be understood that in grouping together certain deposits under the common name of earlier drift, no assertion is made as to the age of the respective deposits with reference to each other. From a consideration of the position of the two classes of deposits named above, however, the inference is clear that the amount of erosion since (1) was deposited has been very great, while the amount of erosion since (2) was deposited is comparatively small. It is, therefore, certain that all of the deposits classed as earlier drift are not of the same age. But the evidence afforded by deposits in the Telluride quadrangle is not sufficient to warrant the conclusion that three distinct glacial epochs are to be recognized. It

[1] Cross, *Telluride Folio*, p. 15.

may prove true that the deposits classed as (2) above should be regarded as merely early phases of the more recent epoch; but additional evidence from adjacent territory is needed before the matter can be placed beyond question.

The age of the oldest of the earlier drift as indicated by the amount of erosion which has taken place since the deposit was made is probably best shown on the mesa on which Diamond Hill is located. The vertical range of the earlier drift in this area is from 9,300 to 10,100 feet in elevation; the pre-glacial surface of the mesa must, therefore, have had a relief of about 800 feet; for the underlying rocks are here chiefly sandstones or igneous rocks, so that any considerable lowering of the surface due to solution as might have been the case in a limestone region cannot have occurred. Between areas of drift now at approximately the same elevation, valleys half a mile broad and 100 to 150 feet deep exist. The slopes of these valleys are gentle, the tops of the hills and ridges rounded or flattened, and undrained depressions are practically unknown. When it is remembered that most of the valleys separating the isolated patches of earlier drift are occupied by temporary streams only, and that for a considerable period the climate of the region has been semiarid, it is evident that the time represented by post-glacial erosion on this mesa is very long.

In considering the relation of the oldest of the earlier drift to that of the more recent epoch, one feature seemed especially prominent as the fieldwork was in progress; that is, the presence of large San Juan bowlders as the most conspicuous constituent of the more recent drift from the main valley of the San Miguel, and similarly, equally large Potosi rhyolite bowlders, characteristic of the oldest of the earlier drift on the mesas and ridges adjacent to the same stream. The presence of large bowlders of a given formation in abundance in drift of a certain period at once raises questions as to the conditions under which glaciers get possession of an abundance of large rock fragments. Judging from the composition of the drift brought down the main valley of the San Miguel to Keystone, and from the relation of the exposures of the various formations in the upper valleys tributary to the San Miguel, it would seem that an abundance of large bowlders in drift is to be

considered as an indication of "plucking" in the bottom of glaciated valleys. It is conceivable that the process of sapping might result in large blocks of rock outcropping above the surface of the ice to fall and be carried on the surface; and there can be no doubt that this sometimes occurs. But in the case of the cirques tributary to the San Miguel River, the summit of their bounding walls consists of an almost continuous ridge of Potosi rhyolite ranging up to about 1,000 feet in vertical extent, 500 feet or more of which was probably all the time above the surface of the glaciers filling the cirques. Yet in the drift left by the ice from these valleys, the Potosi rhyolite is indistinguishable except in small fragments. On the other hand, the San Juan formation, which occurs in the drift in abundance in bowlders up to 18 feet in diameter, outcrops in the lower part of the cirque valleys from 10,000 to 12,000 feet in elevation, and presents in many places the precipitous walls in the bottoms of the valleys transverse to the streams which have been referred to as giving to these valleys a roughened, unglaciated appearance when viewed from below. The appearance of the faces of these cliffs transverse to the valleys is such as would result if the rock were plucked off in large masses. If sapping had any considerable share in supplying the large bowlders of the San Juan formation found near Keystone, it must have occurred at the points where valleys such as Bridal Veil Creek and Marshall Creek join the San Miguel. Here the San Juan formation was exposed in precipitous walls 1,500 to 2,000 feet above the surface reached by the ice. There is no evidence, however, that lateral erosion at these points was sufficient to amount to undercutting; the walls are precipitous but not roughened as if by the removal of large blocks, and the débris which is now falling is for the most part small fragments.

The other drift deposits of the more recent epoch are not characterized by large bowlders. Drift brought by the Lake Fork Glacier is characterized by diorite-monzonite bowlders rarely over 3 or 4 feet in diameter. This formation outcrops in the bottom and sides of the valley in the neighborhood of Ophir Station where precipitous plucked faces occur. Here also the upper slopes of the sides of the valley above the elevation reached by the surface of the

ice may be considered as possible sources of fragments; but they present no evidence of undercutting or of sapping.

It will require much more extended observation to determine without question what the precise relation may be between the average elevation of an area of glaciation and the horizon of a formation prominently represented in the drift by large fragments. But the evidence, as far as observations in the valleys of this quadrangle are concerned, points to the conclusion that an abundance of large bowlders of a certain formation in the drift from a given glaciated area indicates an outcrop of the formation in the bottom and sides of the middle and lower parts of the high valleys in which the glaciers in question were formed. As the San Juan formation lies at approximately 10,500 to 12,000 feet in elevation for its lower and upper limits, respectively, and as the Potosi rhyolite has its lower limit at about 12,500 feet elevation, we should have, on the basis of the foregoing conclusion, a position of the middle part of high glaciated valleys in the earlier drift epoch of not less than 1,000 feet above the level of the present cirque valleys. Or, in other words, that sufficient time has elapsed since the period of the earlier glaciation in this region to permit the removal by erosion in the high mountain tracts of not less than 1,000 feet of igneous rock. This interval of time manifestly must include (1) an interglacial interval, which presumably was of long duration, and (2) the period of more recent glaciation.

POST-GLACIAL CHANGES

The changes due to agencies acting in post-glacial time are chiefly the formation of alluvial cones and fans, alluvial and lacustrine deposits along streams and in lakes or ponds, and talus slopes, and in the renewal of the process of downward cutting by streams in nearly all the valleys. Of the deposits named, the accumulations of talus are largest in amount, slopes of talus 1,000 feet or more in length occurring in a few places. But the total amount of all the post-glacial deposits is insignificant; they are, in general, recognizable only at the base of cliffs or steep slopes and at certain places in the bottoms of valleys. The amount of post-glacial erosion is also in all cases relatively very small; the materials of the drift

generally present a fresh, unweathered appearance; undrained depressions in morainal tracts are still numerous; and streams have cut channels in bed rock not more than 10 to 20 feet in depth in the more favorable locations.

GLACIATION AS AFFECTING THE LOCATION OF MINING CLAIMS

It is reported that the first prospectors in this region found some exceptionally large fragments of ore-bearing rock on the lower slopes of valleys now known to have been glaciated; small fragments are still occasionally met with. In a few cases it seems that these fragments have been taken to be an indication of an outcrop of a vein near by, and considerable effort has been expended in driving tunnels into the underlying bed rock in search of the ore body from which the fragments came. It should be remembered, however, that if fragments of ore-bearing rock are found on the surface within the area shown to have been glaciated, they have little value as indicating that the parent vein or ledge is near at hand. This is particularly true of those parts of valleys in which moraines are found; fragments found in the upper parts of valleys which are comparatively free from débris are more likely to be but a short distance from the outcrop of the body of ore. But the general rule is nevertheless in all cases to be recognized, that fragments found on the surface in any part of a glaciated area may have been derived from a ledge close at hand, or may have been brought from any point in any part of the valley above.